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(71) Applicant: ZIMMERMAN CONSULTING, L.L.C. [US/US]; 3269 Columbus Court, Ann Arbor, MI 48103 (US).

(72) Inventor: ZIMMERMAN, H., Allen; 3269 Columbus Court, Ann Arbor, MI 48103 (US).

(74) Agent: CAMPBELL, James; Klarquist, Sparkman, Campbell, Leigh & Whinston, LLP, One World Trade Center, Suite 1600, 121 S.W. Salmon Street, Portland, OR 97204 (US).

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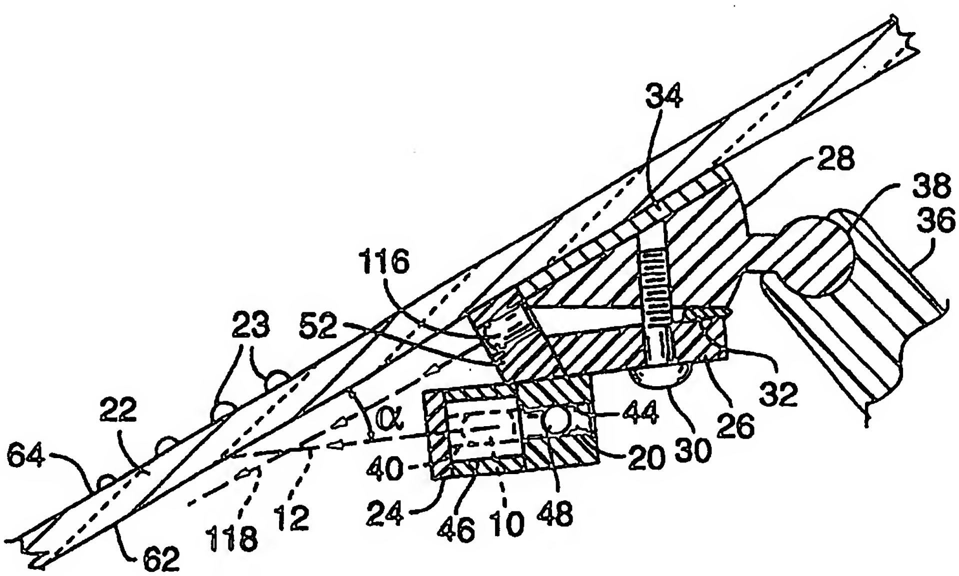

(57) Abstract

A water droplet detection apparatus is disclosed which detects raindrops (23) on the outer surface of a windshield (22) of a vehicle even in the presence of fog droplets on the inner surface of the windshield. A first light beam (12) is transmitted through the windshield to the raindrops which redirect the light beam and cause a portion of it to be transmitted to a photodetector (20), which causes a detector circuit (Figures 5, 6A and 6B) to produce a rain output signal that increases in the amount of raindrops on the windshield. The first light beam strikes the inner surface of the windshield at an acute angle of about 40 degrees or less so that it is not redirected by the fog droplets to the photodetector to produce a false rain signal. A second light beam (14) may be transmitted through the windshield to the photodetector to determine the light transmissivity of the windshield.

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OPTICAL DETECTION OF WATER DROPLETS ON VEHICLE WINDOW

FIELD OF THE INVENTION

The subject matter of the present invention relates generally to optical detection of water droplets on a window, such as the windshield, of an automobile or other motor vehicle. A light beam is transmitted through the window to raindrops or other water droplets on the outer surface of the window which refract the light beam and redirect the light beam to a photodetector which produces a detection signal that increases in amplitude with an increased amount of water droplets on the window. The water droplet detector apparatus of the present invention is useful for detecting raindrops on the outer surface of a windshield even when fog droplets are present on the inner surface of the windshield. The light beam is transmitted at an acute angle to the windshield such that when a portion of such light beam is redirected by the fog droplets on the inner surface of the windshield it is not received by the photodetector. However, when another portion of such light beam is refracted by water droplets on the outer surface of the window it is redirected along a path so that it is detected by the photodetector. Thus, light beam reflections from the fog droplets do not give a false indication of water droplets on the outer surface of the windshield by increasing the output signal of the photodetector.

BACKGROUND OF THE INVENTION

The water droplet detection apparatus of the present invention is an improvement over my earlier U.S. Patent 5,386,111 of H.A. Zimmerman issued January 31, 1995 and the prior art patents cited therein. The water droplet detection apparatus of the present invention differs from that of my prior patent, among other ways, by not employing a mask for blocking the direct transmission of light from a first light source, such as a LED which emits infrared light, to the photodetector. Instead the water droplet detector apparatus of the present invention supports the first light source and the photodetector to produce a first light beam which is directed at an acute angle to the window or windshield so that the light beam is not reflected from the windshield directly to the photodetector. However, when such first light beam is transmitted into water droplets on the exterior of the windshield it is redirected and transmitted to the photodetector. The result is that the output signal of the photodetector increases in amplitude as the amount of raindrops increases on the surface of the windshield.

In addition, the water droplet detection apparatus of the present invention is capable of detection of raindrops in spite of the fact that fog is present on the inner surface of the windshield. Thus, the first light beam is directed at an acute angle of about 40 degrees or less to the windshield such that the fog droplets on its inner surface do not reflect such light beam to the photodetector. The photodetector apparatus of the present invention also employs a second light source for measuring the light transmissivity of the windshield by transmission of a second light beam through such windshield and reflection of the second light beam from the outer surface of

the windshield to the same photodetector used to detect the rain droplets. This enables the detector circuit connected to the output of the photodetector to produce a transmissivity signal to compensate for any changes in the light transmissivity of the windshield when a different windshield is used such as a replacement for a broken windshield.

It has been previously proposed in U.S. Patent No. 4,871,917 of O'Farrell et al. issued October 3, 1989, U.S. Patent 5,262,640 of Pervis et al. issued November 16, 1993, and U.S. Patent 5,323,637 of Bendicks et al. issued June 28, 1994, to provide a water droplet detection system for a vehicle windshield including a light source, such as a light emitting diode, and photodetector which are positioned at an angle with respect to the windshield so that light emitted from such light source is reflected off of such windshield directly into the light emitting diode. Any water droplets on the outer surface of the windshield cause a portion of the light beam to be scattered rather than reflected to the photodetector thereby reducing the output signal of the photodetector. Also, the water droplet detectors of these prior art patents are of limited usefulness because of their small sensitive detection area. In addition, the water droplet detectors of these prior art patents have the disadvantage that they are mounted directly on the windshield of the automobile where they reduce visibility through such windshield and create problems when the windshield must be replaced.

The moisture sensor of the Pervis Patent No. 5,262,640 employs an intermediate layer of adhesive for bonding the mounting block of the detector directly to the inner surface of the windshield. This has the added disadvantage that the bonding material is not of sufficient light optical quality to be light transparent and thereby reduces the amount of light which is reflected back to the photodetector. In the O'Farrell Patent No. 4,872,917 the water droplet detector mounting block is releasably supported by a complicated support mechanism so that it resiliently engages the inner surface of the window. In addition, it employs two photodetectors including an added reference photodetector which increases complexity and cost.

In the Bendicks et al. Patent No. 5,323,637 the mounting block of the water droplet detector is adhesively secured to the inner surface of the windshield and therefore suffers the same disadvantage as the previously described Pervis Patent. However, the adhesive employed in the Bendicks et al. Patent is apparently not positioned in the beam path.

It has been previously proposed in U.S. Patent No. 5,313,072 of Vachss issued May 17, 1994, to provide a water droplet detector employing an optical imager and a photodetector array. The photodetector is a two dimensional array of photo diodes which are connected to the inputs of a microprocessor computer. The computer processes the output signals of the photo diodes for measuring the intensity of a different portion of the light image detected by such photo diode array. The computer analyzes the intensity of the off axis light versus the intensity of the on axis light to determine whether obscuring moisture in the form of the raindrops is present on the windshield. This is a much more complicated and expensive apparatus than that of the present invention and apparently is of questionable accuracy.

It has been proposed in PCT Application No. 94/05093, Publication No. W094/27262 of Hegyi published November 24, 1994, to provide a multi-function light detector for a vehicle which detects water droplets on the outer surface of the windshield by using an apertured baffle which functions as a mask. A light beam is projected through one baffle aperture by a light source and reflects off the windshield to the baffle while a portion of the beam is scattered by the raindrops and caused to be redirected through a second baffle aperture to the photodetector for producing a rain output signal indicating the presence of raindrops. The rain signal is blocked or distorted by fog on the inner surface of the windshield or by smoke with the passenger compartment of the vehicle. Also, fog or smoke produce strong output signals which are easily confused with rain signals. The detector circuit produces an additional output signal corresponding to the ambient light signal and a sensitivity signal which together with the rain signal are all applied to the inputs of a microprocessor computer. The computer produces control signals which control the windshield wiper to remove the raindrops, the dehumidifier to remove fog, and the ventilator to remove smoke. As a result the photodetector of Heygi cannot detect raindrops separately from fog or smoke. Instead the photodetector produces a combined output signal including a raindrop signal and signal portions corresponding to the presence of fog or smoke. Thus the raindrop signal is detected by differentiating it from the combined output signal produced by the photodetector. The baffle plate which acts as a mask is provided on the dashboard of the vehicle so that the light source and the photodetector are positioned below the dashboard and are looking upward through apertures in the baffle into the sky so they would be highly effected by direct exposure to the sunlight and or streetlights which produce large ambient light signals. Apparently the central axis of the light beam emitted by the LED light source and the central axis of the viewing field of the photodetector both form an angle of about 90 degrees with respect to the inner surface of the windshield. Thus the angle of the light beam with respect to the windshield is much greater than 40 degrees and as such, is not sufficiently small to prevent reflection of the light beam by the fog particles back to the photodetector and thereby permit the detection of raindrops on the outer surface of the windshield in the presence of fog on the inner surface of the windshield in the manner of the present invention.

The term "light" as used herein refers to both visible light and invisible light such as infrared radiation. Thus, preferably the light source is a light emitting diode (LED) which emits infrared light and the photodetector detects such infrared light. However, the light source and photodetector may also use visible light.

The water droplet detector apparatus of the present invention employs a detector circuit with optically coupled negative feedback to eliminate that portion of the photodetector output signal corresponding to ambient light and to make the photodetector function as a null detector. The feedback detection circuit is similar to that disclosed in my earlier U.S. Patent 5,386,111 referred to above. However, the circuit of the present invention does not employ a fog measurement LED but instead employs a transmissivity measuring LED which measures the

transmissivity of the windshield to adjust system sensitivity due to changes in the windshield material. Alternatively, the transmissivity LED may be replaced with a smoke LED which emits a third light beam in a downward direction substantially parallel to the windshield in order to detect smoke within the passenger compartment of the vehicle. The transmissivity LED or the smoke LED together with the two rain LEDs and the bias LED provide three optical signal inputs (one at a time) to the same photodetector at the input of the detection circuit. As in my prior Patent the bias LED is connected in the negative feedback circuit and provides optical coupling to the photodetector for such negative feedback and to bias the photodetector to its desired operating point of high sensitivity.

SUMMARY OF THE INVENTION

It is therefore one object of the present invention to provide an improved water droplet detection apparatus of high accuracy and sensitivity in which rain and other water droplets on the outer surface of a vehicle windshield or other window are detected using a light source which directs a first light beam through the window and a photodetector positioned to detect a portion of the first light beam redirected by the water droplets to the photodetector in order to increase the amplitude of the output signal of such photodetector with a increased amount of water droplets.

Another object of the invention is to provide such a water droplet detector apparatus of simple and inexpensive construction which is capable of detecting water droplets on the outer surface of the window even though fog is present on the inner surface of the window by directing the first light beam to the window at an acute angle of 40 degrees or less.

A further object of the invention is to provide such an improved water droplet detection apparatus which does not employ a light mask in front of the photodetector to prevent the direct transmission to such photodetector of the light beam unless such light beam is redirected by the water droplets.

An additional object of the present invention is to provide such an improved water droplet moisture detection apparatus in which a transmissivity light source is employed to direct a second light beam through the windshield to the photodetector in order to measure the light transmissivity of the windshield with the same photodetector and to adjust the sensitivity of the photodetector circuit for raindrop measurements corresponding to such transmissivity.

Another object of the invention is to provide a smoke detection light source which directs a second light beam downward and substantially parallel to the inner surface of the windshield to detect smoke within the passenger compartment of the vehicle by scattering such light with smoke particles to cause a portion of the second light beam to be received by the photodetector.

Still another object of the invention is to provide an improved water droplet detection apparatus employing a detection circuit using optically coupled negative feedback to provide a more accurate detector circuit output signal which is representative of the amount of raindrops present on the surface of the window.

A still further object of the invention is to provide such a water droplet detection apparatus in which a third light source employed as a bias light source to bias the photodetector at the proper operating point of high sensitivity, such third light source being used for optically coupling the negative feedback signal to the photodetector.

An additional object of the invention is to provide such a water droplet detection apparatus in which the detection circuit includes a current driving pulser circuit connected to the light sources for pulsing such light sources on and off to produce a pulsed photodetector output signal and narrow band amplifier including a charge integrator amplifier and an inverting amplifier whose output is connected to a charge memory circuit by a time-slot switch which is synchronized to the pulsed driving circuit.

Still another object of the invention is to provide an improved water droplet detection circuit in which the first light beam for detecting the rain droplets is produced by a pair of light emitting diodes which are spaced apart and have their two beam axes intersecting at a common point on the viewing axis of the photodetector so that the two portions of the light beam overlap at the windshield to produce a larger area of detection for the raindrops to enable more efficient operation of the raindrop detector apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and advantages of the present invention will be apparent from the following detailed description of a preferred embodiment thereof and from the attached drawings of which:

Figure 1 is a sectional side view of the water droplet detection apparatus of the present invention supported adjacent a vehicle windshield;

Figure 2 is a section view taken along line 2-2 of Figure 1;

Figure 3 is a vertical section view taken along the line 3-3 of Figure 2;

Figure 4 is an enlarged view of a portion of the windshield having fog particles on the inner surface of such windshield showing their effect on light beams of different angles;

Figure 5 is a diagram of a detector circuit connected to the output of the photodetector employed in the water droplet detector apparatus of Figures 1 to 4.

Figure 6A is a detailed electrical circuit of an input portion of the detector circuit of Figure 5;

Figure 6B is a detailed electrical circuit diagram of an output portion of the detector circuit of Figure 5; and

Figure 7 is a sectional side view of a second embodiment of the water droplet detection apparatus of the present invention which also detects smoke.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

As shown in Figs. 1, 2, and 3 one embodiment of the water droplet detection apparatus of the present invention includes a pair of first light sources 10 and 11 which may be light emitting diodes that emit two light beams of infrared light each having a central beam axis 12 and 14 respectively. The light beams 12 and 14 are directed inwardly toward each other and intersect at a point 16 on the central viewing axis 18 of a single photodetector 20. The photodetector 20 may be a infrared sensitive photo transistor which produces an electrical output signal upon receipt of infrared light, as hereafter discussed with respect to Fig. 5. The two light beams emitted by light emitting diodes 10 and 11 overlap each other at the vehicle windshield 22 in order to increase the detection area for detecting water droplets 23 on the windshield, which is in the viewing field of the photodetector 20. The light emitting diodes 10 and 11 and photodetector 20 are mounted on a common support 24 which may be attached to the rear view mirror. The common support includes a mounting flange 26 that is fixed to a rear view mirror mount 28 by a pair of screws 30. A resilient spacer 32 of rubber or other elastomer material is compressed between the mounting flange 26 and the mirror support 28. The resilient spacer 32 maintains the water droplet detection apparatus and its support 24, 26 in a fixed position relative to the windshield 22 when the mounting screws 30 are tightened into the final fastening position. It should be noted that the rear view mirror mount 28 is fixed to the inner surface of the windshield 22 in any suitable fashion such as by means of an adhesive layer 34 while allowing such rear view mirror to be adjusted by a universal pivot 38 on such mirror mount.

As shown in Fig. 1 the central axis 12 and 14 of the light sources 10 and 11 intersect the inner surface of the windshield 22 by an acute angle α of 40 degrees or less so that the light beams are not reflected by fog on the inner surface of the windshield or otherwise redirected by imperfections on such inner surface directly to the photodetector 20. It has been found that an angle of 24 degrees between the beam axis and the inner surface of the windshield is preferable for optimum results.

As shown in Fig. 2 the light emitting diodes 10 and 11 may be mounted within circular passages 40 and 42, respectively, in the common support 24 which is of light opaque plastic material, to support the light emitting diodes at the proper angle so that their beam axes 12 and 14 each intersect the viewing axis 18 at an angle β of approximately 35 degrees for partial overlap of the light beams emitted by such light emitting diodes. It should be noted that the two light beams 12 and 14 overlap partially at the windshield and combine to form a first light beam of larger detection area which is redirected by raindrops 23 on the outer surface of the windshield to the photodetector 20. In addition the passages 40 and 42 function as collimators to limit the light beams emitted by such photodiodes to narrow beams having central axis 12 and 14. In addition, the photodetector 20 is also mounted in a cylindrical passage 44 within the common mounting member 24 so that its viewing field is also limited or collimated about its axis 18.

However, the mounting passage 44 intersects with a larger diameter passage 46 through the outer portion of the common support 24.

A bias light source 48 is mounted on the common support 24 for transmitting a second infrared light beam directly to the photodetector 20 to bias such photodetector to an operating point of high sensitivity to infrared light in a manner here after discussed with respect to the circuit of Figs. 5 and 6A. This bias light source 48 is a LED which emits infrared light and functions as an optical feedback element in the negative feedback path of the detector circuit shown in Fig. 5 and 6A. The bias light source 48 is mounted within an aperture on the common support 24 with its light beam axis perpendicular to the photodetector as shown in Fig. 2.

As shown in Fig. 1 and 3 a third light source 50 may be provided on a mounting block 52 fastened to common support and is of similar plastic material to that of the common support 24. The mounting block 52 may be fastened by adhesive to the upper surface of the common support 24 and is provided with a mounting passage 54 for a LED serving as the third light source 50. This third light source 50 emits a third light beam along axis 57 which functions as a transmissivity measuring light beam. The light beam 57 is directed to the windshield 22 so that it is reflected off the outer surface of such windshield to the photodetector 20 to measure the light transmissivity of the windshield 22 to permit compensation for changes in transmissivity of different windshields, such as the replacement windshield of a vehicle whose original windshield is broken. A pair of transparent light pipes 56 and 58 may be provided including a first light pipe 56 between the light source 50 and the windshield and a second light pipe 58 between such windshield and the photodiode as shown in Fig. 3. The light pipes 56 and 58 may be cylinders of light transparent acrylic of approximately 0.125" diameter and are each angled at an angle of approximately 20.9 degrees with respect to a center axis 60 perpendicular to such windshield at its outer surface. As a result the transmissivity path of the light beam from the third light source 50 to photodetector 20 passes through the windshield from the inner surface 62 to the outer surface 64 and is reflected back from the outer surface through the inner surface to the photodetector 20. The resulting transmissivity output signal produced by the detector circuit indicates the light transmissivity of the windshield.

As shown in Figs. 4A and 4B when fog droplets 66 are present on the inner surface 62 of the windshield 22 they affect the path of the combined first light beam emitted from the first light sources 10 and 11 which includes light rays 68 that are directed to strike the inner surface of the windshield 22 at a angle of 40 degrees or less and preferably at an angle of approximately 24 degrees. As shown in

Fig. 4B when the first light beam emitted by light sources 10 and 11 travels along light rays 68 such light rays strike the fog droplets 66 and are internally reflected by such fog droplets so that such internally reflected rays are effectively blocked by neighboring fog particles and are not returned back to the photodetector 20 so that they do not cause such photodetector to produce a false rain output signal. As a result the raindrops 23 on the outer surface 64 of the windshield

are detected by the remaining portion of the first light beam which is internally reflected and refracted by such raindrops and returned back along the same direction as the incident light rays 68 to the photodetector which causes the detector circuit to produce an accurate rain signal. However, if the angle of impingement of the first light beam with the inner surface 62 of the windshield is greater than 40 degrees, as indicated for the light beam rays 70, a portion of, the light beam is internally reflected within the fog particles and returned back along the same beam path so that such reflected light beam is received by the photodetector which then causes the detector circuit to produce a false rain signal corresponding thereto. As a result, the water droplet detection apparatus of the present invention detects rain droplets on the outer surface 64 of the windshield even in the presence of fog droplets on the inner surface of the windshield. It should be noted that the presence of fog droplets on the inner surface of the windshield will scatter light and reduce the rain signal produced by the photodetector because it reduces the intensity of the light beam which is redirected by the rain droplets back to the photodetector. However this reduction in amplitude of the detector output signal corresponding to such rain droplets is very small and may be ignored.

As shown in Fig. 7 another embodiment of the water droplet detection apparatus of the present invention which detects smoke, is similar to the embodiment of Figs. 1-3 but includes a second light source 116 in place of light source 50, that may also be an infrared light emitting diode (LED) which emits a second light beam along beam axis 118. The second light beam 118 is directed downward along the inner surface 62 of the windshield and may be substantially parallel to such inner surface so that smoke particles within the passengers compartment of the vehicle scatter the second light beam and cause a portion of it to be received by the photodetector 20. The smoke signal output of the detector circuit can be sensed to either shut down the rain detection circuit before it produces a false rain signal or it may be used to temporarily reduce the sensitivity of the rain detection circuit to avoid a false rain signal response but to continue to respond to raindrops. By pointing the second light source down, it also senses the intrusion of hands or other objects into the detection region and may be used to shut down the raindrop detection system.

As shown in Fig. 5 the photodetector circuit includes a charge integrator circuit 72 connected at its input to the collector of the photodetector transistor 20 through a coupling capacitor 74. A shunt capacitor 76 is connected from the output to the input of an inverter amplifier within the charge integrator. The output of the charge integrator 72 is connected to an inverting amplifier 78 through a coupling resistor 80 and a negative feedback resistor 82 as connected from the output to the input of such inverting amplifier. The output of the inverting amplifier 78 is connected through a coupling capacitor 84 in series with a coupling resistor 86 to the input of a Miller memory circuit 88. The memory circuit includes an inverter amplifier with a shunt capacitor 90 connected from its output to its input serving as the memory capacitor. The output of the Miller memory circuit 88 is the output of the detector circuit and is connected

through a negative feedback path including a first feedback resistor 92 in series with a second feedback resistor 94. The feedback path is optically coupled to the phototransistor 20 through the bias and feedback light source 48.

The water droplet or rain light sources 10 and 11 are connected in series to a pulsed drive circuit including pulser 96 which applies square wave current pulses through a drive resistor 98 to the rain LEDs 10 and 11. The pulses turn such LEDs on and off at a predetermined frequency. When the rain LEDs 10 and 11 are pulsed on they produce a photodetector output current pulse I_1 on the collector of photodetector transistor 20. As a result of negative feedback the bias and feedback LED 48 is pulsed on during the second time slot to produce a photodetector collector current pulse I_2 which is 180 degrees out of phase with respect to the current pulse I_1 produced by the rain LEDs and produces a collector current change of $I_1-I_2 = \Delta I$. The pulsing of the feedback current I_2 180 degrees out of phase with the pulsed rain output signal I_1 is accomplished by a timeslot switch 100 synchronized with the pulser 96, which alternately grounds a first common connection between the coupling capacitor 84 and the coupling resistor 86 at switch position 2, and a second common connection between the two feedback resistors 92 and 94 at switch position 1. As a result of this operation of the time slot switch 100 in synchronism with the current pulser 96 of the rain LEDs, the feedback current I_2 is effectively subtracted from the rain output current I_1 of the photodetector 20 to produce the difference signal ΔI. This difference signal is applied to the charge integrator 72 to cause such integrator to produce a positive triangular integrator output voltage change $\Delta V3$ at the output of the charge integrator 72. It should be noted that this would be negative if I_2 were larger than I_1. However in Fig. 5, I_2 is shown as being smaller than I_1. The inverting amplifier 78 inverts and amplifies this positive triangular voltage $\Delta V3$ into a negative triangular voltage of $\Delta V4$ of greater amplitude at its output. The timeslot switch 100 is in the upper switch position 2 during the second time slot which enables the feedback operation and charges the coupling capacitor 84 to the peak negative voltage of the inverting amplifier output signal $\Delta V4$. At the start of the next timeslot the timeslot switch 100 is moved downward to its lower switch position 1. As a result the voltage at the output of the coupling capacitor 84 starting at 0 tends to go negative to follow the triangular wave form of the inverting amplifier output signal $\Delta V4$. This produces an intermediate voltage $\Delta V5$ at the common connection of capacitor 84 and resistor 86 causing current to flow through the coupling resistor 86 which serves as a current limiting resistor, to charge the memory capacitor 90. As a result, the output voltage Vout of the Miller memory increases positively. It should be noted that the time constant of resistor 86 and capacitor 84 is kept short so that the charging time of the memory capacitor 90 is approximately equal to the width of the timeslot 1 so that such capacitor is quickly charged to its maximum voltage by current flowing from capacitor 84. The output voltage Vout at the output of the Miller memory 88 is transmitted as a negative feedback signal through feedback resistors 92 and 94 when the timeslot switch is in the upper position 2.

However, such feedback signal is 0 when the time slot switch 100 is in the lower switch position 1 which grounds the common connection of the feedback resistor 92 and 94.

The analog output voltage of the Miller memory 88 is transmitted through an A/D convertor 102 and the resulting digital output signal is fed to a general purpose digital computer 104 where the output signal is processed in a conventional manner to produce the control signals which operate various controls 106 such as the windshield wiper motor, the motor controlling the sunroof or convertible top of an automobile and/or the motor which raises and lowers the side windows of such automobile when raindrops are sensed on the windshield. In addition, an optional digital display device 108 may be connected to the output of the A/D converter 102 in order to display the amplitude of the rain signal. A similar output control and display circuit is shown in Fig. 6 of my earlier Patent No. 5,386,111.

The operation of the photodetector circuit of Fig. 5 is similar to that of my earlier U.S. Patent 5,386,111 except for the differences noted above. The bias and feedback LED 48 functions to bias the photodetector transistor 20 at an optimum operating point which is of high sensitivity to the infrared light emitted by the rain LEDs. Also the optically coupled negative feedback eliminates the ambient light signal from the output signal of such photodetector so that the amplitude of the output signal of the Miller memory more accurately represents the amount of raindrops which have accumulated on the windshield during the detection period.

During the operation of the circuit of Fig. 5 the same two photodetector current components (here called "I_1" and "I_2") are "time sliced" in the same polarity into successive time slots. This is shown in Fig. 5. Even if I_1 and I_2 are only slightly different, this photodetector current wave-form will cause charge to flow alternately in and out of C_1 and C_2 through the action of Amplifier 72. The amount of this charge is:

$Q = IT = (I_1 - I_2) \circ T$, where T is the

duration of each time slot. The integrator circuit 72 formed by Amplifier A_1 and Capacitors C_1 and C_2 causes this alternating current to produce the triangular voltage wave-form ΔV_3 at its output as shown in Fig. 5 having a peak-to-peak amplitude of:

$$\Delta V_3 = (I_1 - I_2) \circ T / C_2$$

The inverter amplifier 78 includes an amplifier A_2 with gain $- R_4 / R_3$ which produces the larger and inverted triangular voltage wave-form $\Delta V4$ at its output as shown in Fig. 5.

Switch 100 closes to position 2 during time slot 2 to allow negative feedback. At the end of time slot 2, C_3 is nearly charged to the peak of the triangular voltage $\Delta V4$. At the start of the following time slot (time slot 1), switch 1 changes the position 1 and the voltage $\Delta V5$ being zero at first then begins to follow the triangular wave-form negatively. This causes current to begin to

flow in current-limiting resistor, R_5, and memory capacitor, C_4, as the output voltage, Vout, of the Miller memory 88 including amplifier 3 moves positively. Time constant, $R_5 \circ C_3$, is kept short with respect to the duration of time slot 1 so that C_3 nearly completely discharges into R_5 -- transferring the following charge into C_4:

$$Q = CV = C_3 \circ R_4/R_3 \circ \Delta V_3 \qquad \text{or}$$

$$\Delta Vout - C_3/C_4 \circ R_2/R_3 \circ (I_1 - I_2) \circ T/C_2$$

Note that the amplitude of the output step, ΔVout, is proportional to $(I_1 - I_2)$ causing ΔVout to be zero when $I_1 = I_2$ and causing ΔVout to step negatively when $I_2 > I_1$.

Vout is presented to both the following A/D converter 102 and to the feedback loop 92, 94, 48. Equilibrium is reached after the difference signal, ΔI at output of photodetector, has stepped the output-voltage by the correct amount and direction so as to cause the photodetector feedback-current component (I_2) to equal the rain (or fog) signal-current component (I_1). The number of steps required to reach equilibrium depends on the difference, $(I_1 - I_2)$, and the forward gain of the entire system.

The detailed electrical circuit of the detector circuit diagram of Fig. 5 is shown in Figs. 6A and 6B, and is similar to that of Fig. 5 but also includes the transmissivity LED 50 (or the smoke LED 116 of Fig. 7) and its associated circuit for measuring the transmissivity of the windshield (or the presence of smoke within the vehicle). A source of driving current pulses 110 is also provided in Fig. 6A for applying pulses through a transistor driver to the transmissivity LED 50 or the smoke LED. Thus the transmissivity LED produces light pulses which are transmitted through windshield and then reflected from its outer surface 64 to the photodetector 20 to produce an output signal at the output of its associated Miller memory 88' in Fig. 6B which is fed through a switch 112 to the output of such memory when such switch is closed. A similar output switch 114 is connected to the output of the Miller memory 88' which stores the rain LED signal in memory capacitor 90, in the operation previously described with respect to Fig. 5.

The transmissivity output signal is fed from Vout terminal 4 of the memory 88' to the analog to digital converter 102 and converted to a digital signal which is applied to computer 104 for modification of the computer output control signals in accordance with the measured transmissivity of the windshield.

Similarly the smoke output signal is fed from the Vout terminal of the memory 88' through the analog to digital converter to the computer 104 causing it to produce a control signal which stops the rain detection and/or reduces its sensitivity.

In view of the many possible embodiments to which the principles of our invention may be applied, it should be recognized that the illustrated embodiments are only a preferred example of the invention and should not be taken as a limitation on the scope of the invention. Rather, the

scope of the invention is defined by the following claims. I therefore claim as my invention all that comes within the scope and spirit of these claims.

We claim:

1. Liquid droplet detector apparatus for a motor vehicle having a windshield, comprising:

first light source for providing a first light beam which impinges upon the windshield at an angle of about 40 degrees or less with respect to the windshield to detect water droplets on the outer surface of said windshield even though fog may be on the inner surface of the windshield;

photodetector; and

a support for supporting the photodetector in position to receive a portion of said first light beam that is redirected by said water droplets to said photo detector and to produce a rain output signal that increases in amplitude with the amount of water droplets on the outer surface of the windshield.

2. Apparatus in accordance with claim 1 in which the first light beam impinges upon the windshield at an angle which prevents the first light beam from being redirected by fog on the inner surface of the windshield to the photodetector or by reflection from the inner surface of the windshield to the photodetector.

3. Apparatus in accordance with claim 1 which also includes a second light source supported in position to transmit a second light beam between the inner surface and the outer surface of the windshield and then to said photodetector to determine the light transmissivity of said windshield.

4. Apparatus in accordance with claim 1 in which the first light source includes two light-emitting semiconductor devices which direct two light beams inwardly toward the viewing axis of the photodetector so that the two beams partially overlap within the viewing area of the photodetector where they intersect the windshield to form the first light beam and to increase the rain detection area.

5. Apparatus in accordance with claim 3 in which a projected portion of each of the two inwardly-directed light beams is reflected by the inner surface of the windshield onto an area of the dashboard of the vehicle which is spatially separated from and does not overlap the similarly-projected sensitive viewing area of the photodetector to prevent such illumination from producing a false rain indication by being re-reflected by the dashboard or by any reflective items which may be placed upon the dashboard.

6. Apparatus in accordance with claim 1 which includes a second light source that transmits a second light beam downward along the inner surface of the windshield to detect

smoke within the vehicle or the intrusion of objects in the detection region of the beam by scattering said second light beam so that a portion is received by said photodetector.

7. Apparatus in accordance with claim 1 which also includes a third light source for transmitting a third light beam directly to said photodetector for biasing said photodetector to its optimum operating point.

8. Apparatus in accordance with claim 7 in which the photodetector is connected to a detector circuit for processing the rain output signal of said photodetector, said detector circuit including a negative feedback path connected from the output of the detector circuit to the third light source which emits the third light beam directly to the photodetector for biasing the photodetector and to provide electro-optical feedback.

9. Apparatus in accordance with claim 8 which also includes a pulsed drive circuit for applying pulsed drive current to the first light source and the third light source, and the detector circuit includes a charge integrator circuit connected to the output of the photodetector and the gain of said detector circuit is determined by said feedback.

10. Apparatus in accordance with claim 9 in which the detector circuit includes a bandpass amplifier connected to the output of the charge integrator circuit.

11. Apparatus in accordance with claim 10 which also includes a memory circuit connected to the output of the bandpass amplifier and the feedback path is connected from the output of the memory circuit to the third light-emitting device.

12. Liquid droplet detector apparatus for a passenger vehicle having a windshield, comprising:

a first light source providing a first light beam including two light beam portions emitted by two light emitting devices so that the two beam portions overlap where they intersect the windshield to form the first light beam, said first light beam portions intersecting the windshield at an acute beam angle which enables the detection of water droplets on the outer surface of the windshield even though fog may be present on the inner surface of the windshield;

a photodetector; and

a support for supporting the photodetector to receive a portion of said first light beam that is redirected by said water droplets to said photodetector and to produce a rain output signal that increases in amplitude with the amount of water droplets on the outer surface of the windshield.

13. Apparatus in accordance with claim 12 in which the two light emitting devices emit the two light beam portions along a first beam axis and a second beam axis which are positioned on opposite sides of the viewing axis of the detector and are inclined inwardly toward the viewing axis at an acute intersection angle to intersect said viewing axis adjacent the windshield so that the two beam portions overlap on the outer surface of the windshield.

14. Apparatus in accordance with claim 13 in which the intersection angle between the beam axis and the viewing axis is about 35 degrees.

15. Apparatus in accordance with claim 12 in which the acute beam angle between the beam axis and the windshield is about 40 degrees or less.

16. Apparatus in accordance with claim 15 in which the beam angle is about 24 degrees.

17. Apparatus in accordance with claim 12 which also includes a second light source supported to transmit a second light beam between the inner surface and the outer surface of the windshield and then to said photodetector to determine the light transmissivity of said windshield.

18. Apparatus in accordance with claim 12 which includes a second light source that transmits a second light beam substantially parallel to the inner surface of the windshield to detect smoke within the vehicle by scattering said second light beam so that a portion of the second light beam is received by said photodetector.

19. Apparatus in accordance with claim 12 which also includes a third light source for transmitting a third light beam directly to said photodetector for driving said photodetector to its bias operating point.

20. Apparatus in accordance with claim 18 in which the photodetector is connected to a detector circuit for processing the output signal of said photodetector including a charge integrator circuit connected to the output of said photodetector, said detector circuit including a negative feedback path connected from the output of the detector circuit to the third light source which emits the third light beam directly to the photodetector for biasing the photodetector and to provide electro-optical feedback, and also includes a pulsed drive circuit for applying pulsed drive current to the first light source and the third light source.

FIG. 1

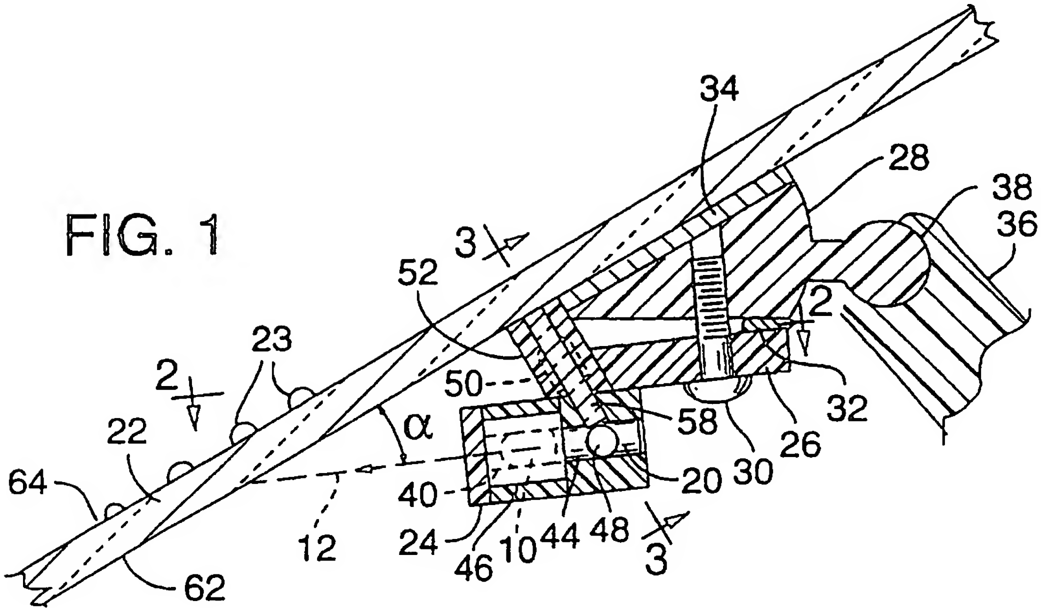


FIG. 2

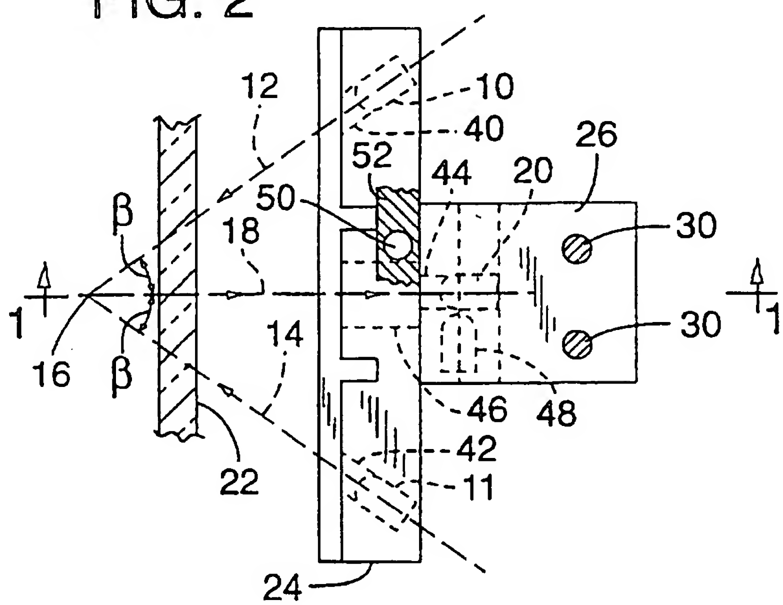


FIG. 3

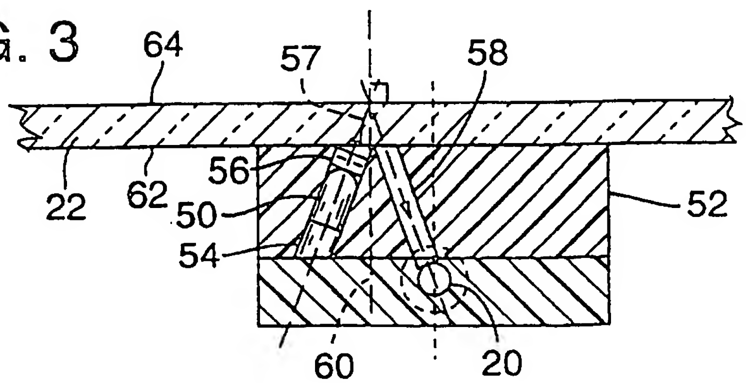


FIG. 4A

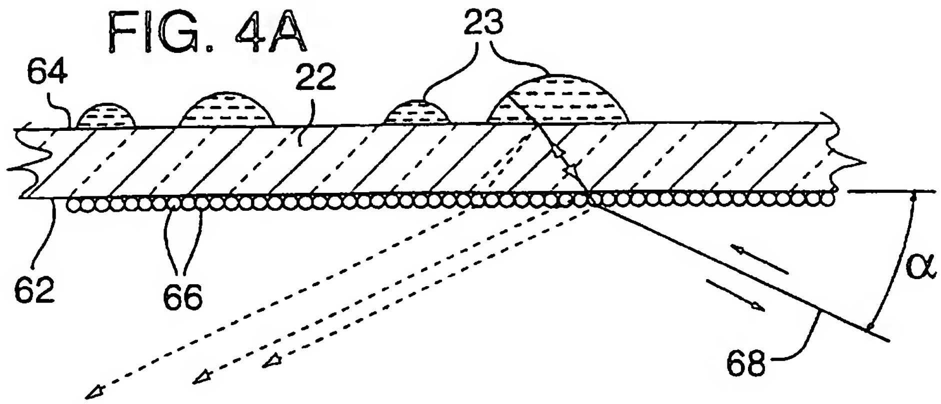


FIG. 4B

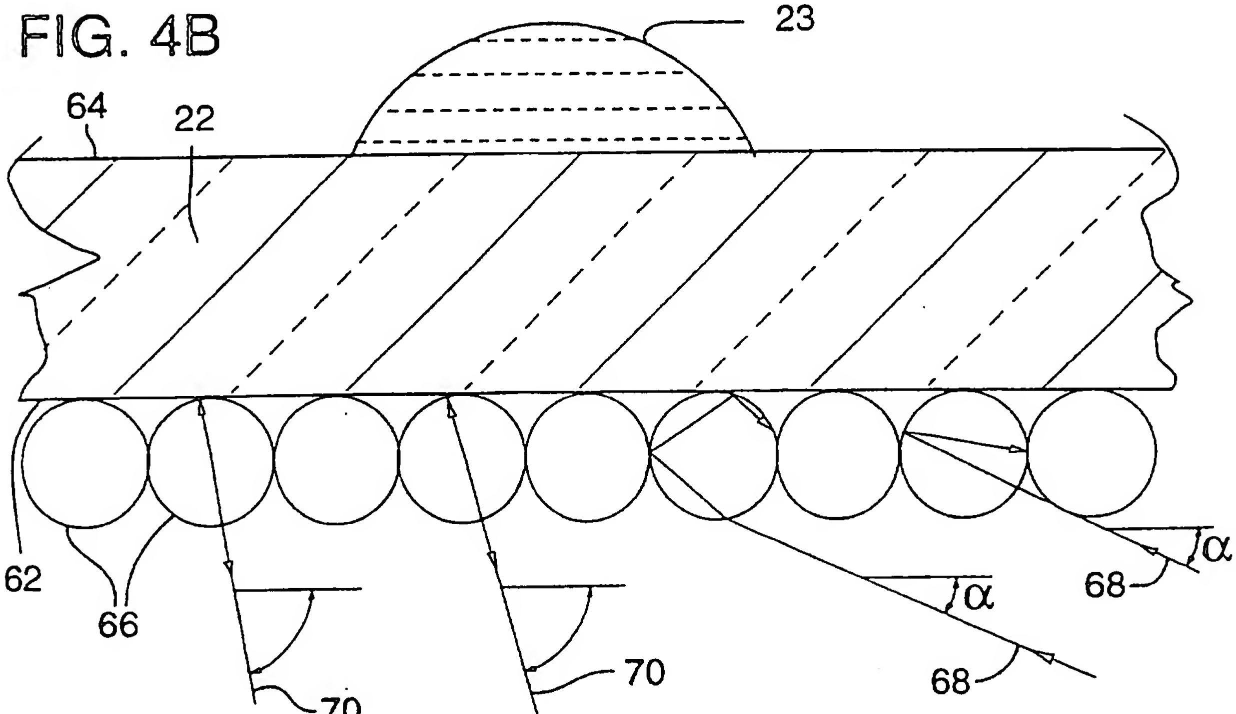


FIG. 7

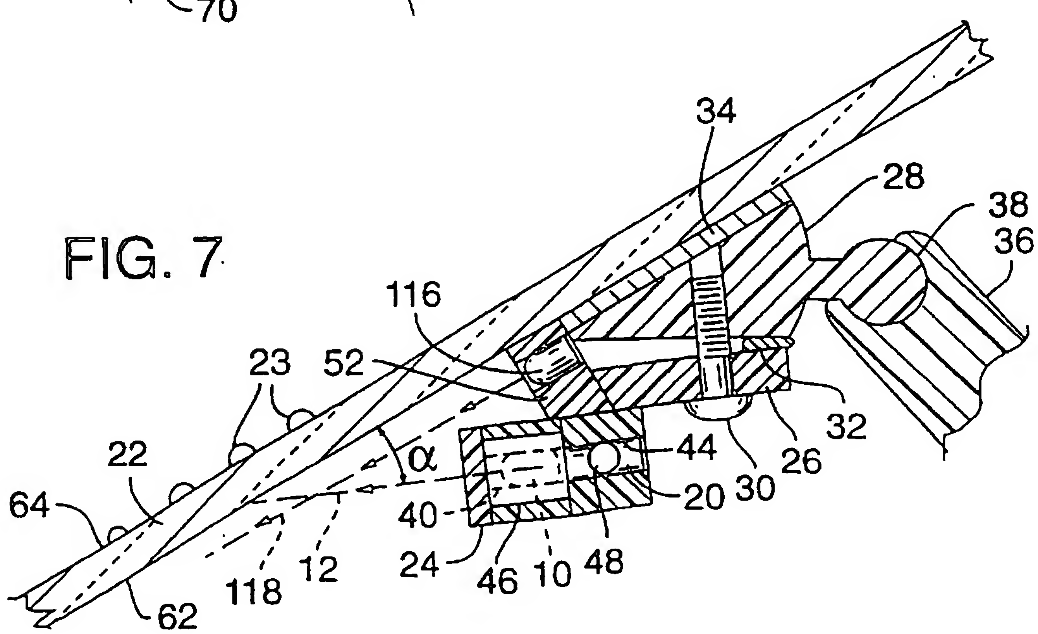
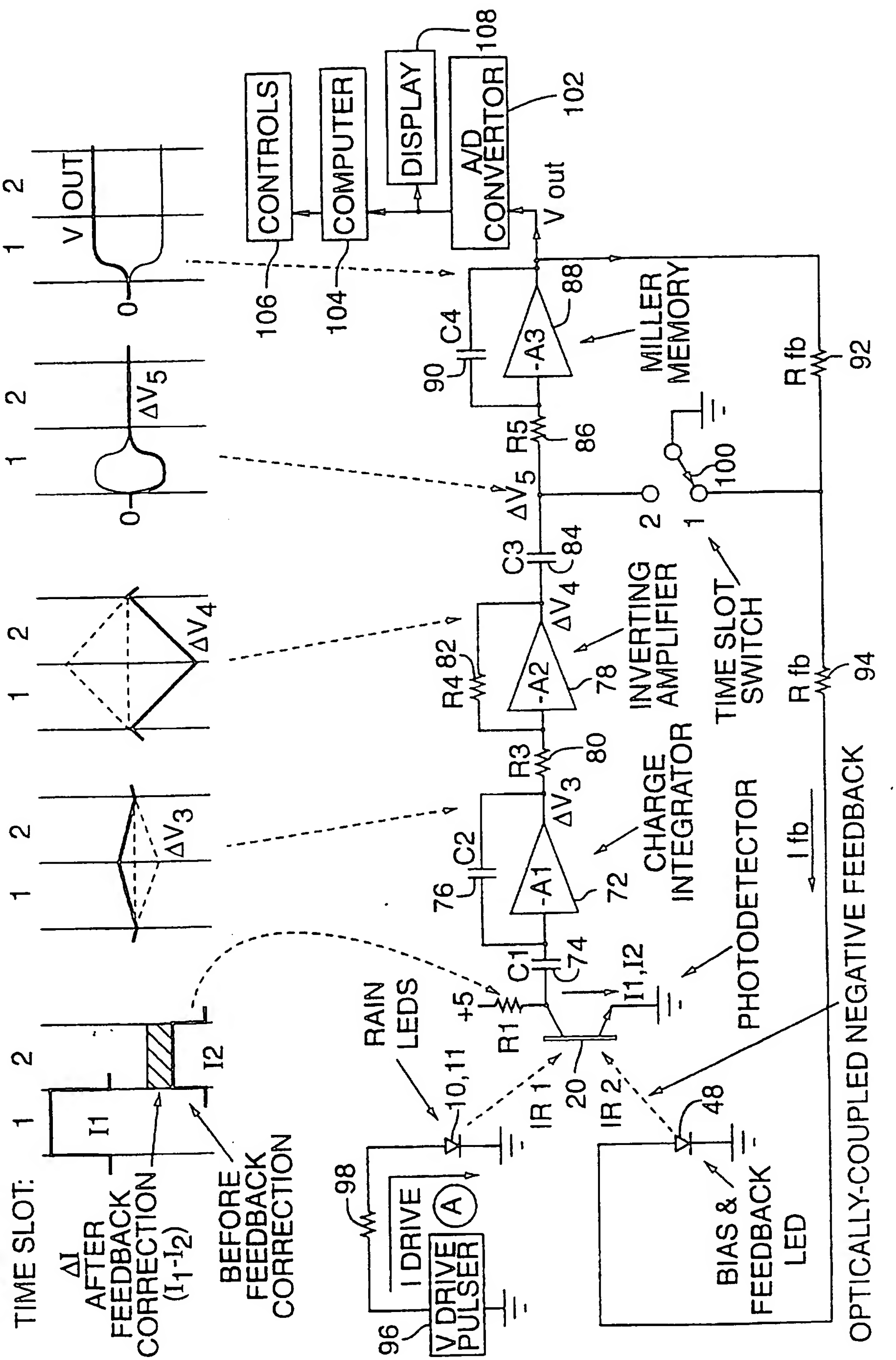


FIG. 5


TIME SLOT:
1
2
ΔI
AFTER
FEEDBACK
CORRECTION
(I1-I2)
BEFORE
FEEDBACK
CORRECTION
I1
I2
ΔV3
ΔV4
ΔV5
0
V OUT
CONTROLS
COMPUTER
DISPLAY
A/D
CONVERTOR
108
102
106
104
V out
88
C4
90
-A3
MILLER
MEMORY
R5
86
ΔV5
R fb
92
100
2
1
TIME SLOT
SWITCH
C3
84
ΔV4
R4 82
-A2
78
INVERTING
AMPLIFIER
R fb
94
R3
80
ΔV3
C2
76
-A1
72
CHARGE
INTEGRATOR
I fb
PHOTODETECTOR
C1
74
I1,I2
+5
R1
RAIN
LEDS
10,11
20
IR 1
IR 2
48
OPTICALLY-COUPLED NEGATIVE FEEDBACK
BIAS &
FEEDBACK
LED
98
I DRIVE
A
V DRIVE
PULSER
96

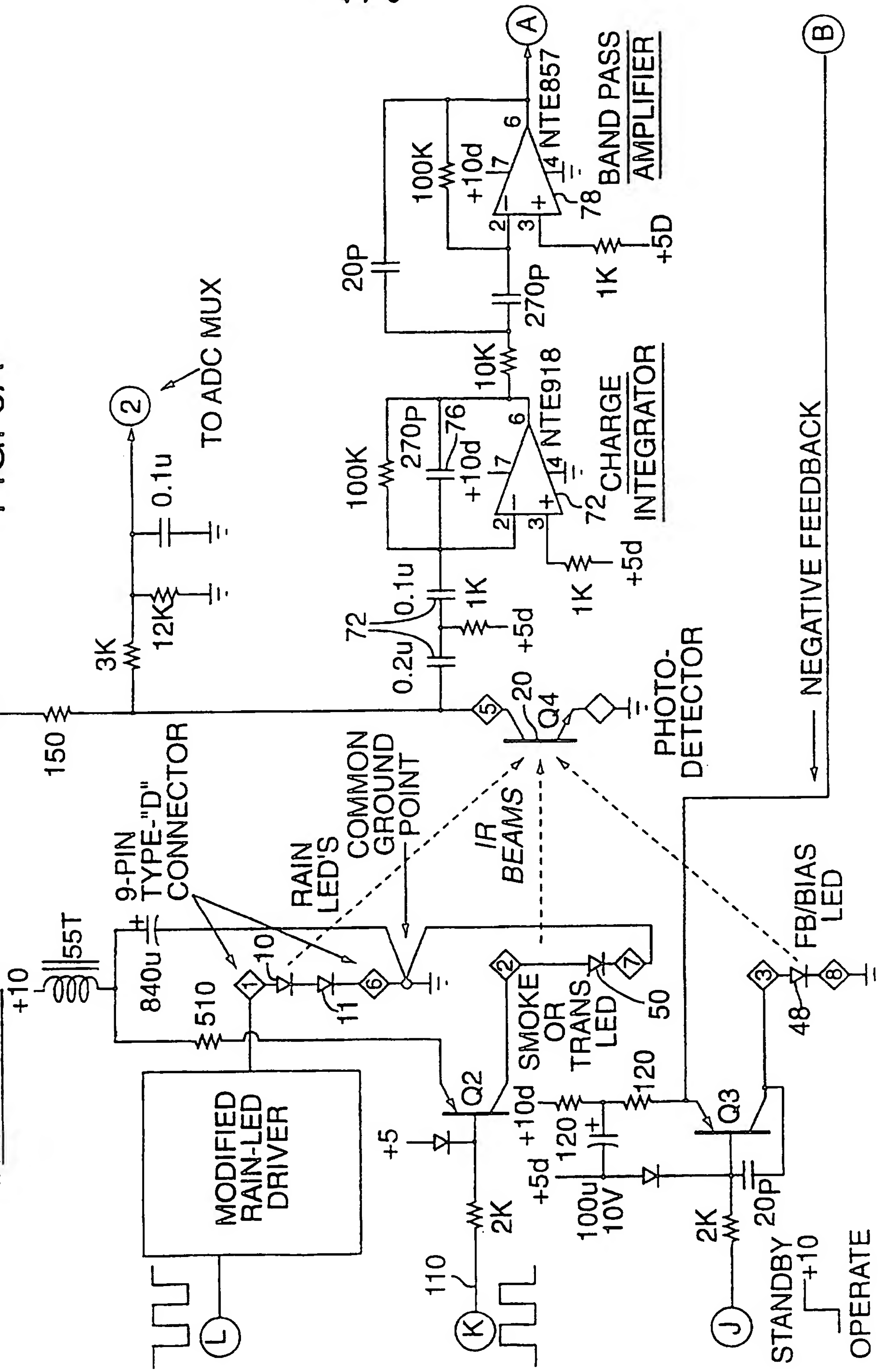

IR-LED DRIVERS
+10
55T
840u
510
9-PIN TYPE-"D" CONNECTOR
MODIFIED RAIN-LED DRIVER
RAIN LED'S
COMMON GROUND POINT
10
11
1
6
L
K
110
2K
+5
Q2
+10d
+5d
120
100u 10V
SMOKE OR TRANS LED
50
2
7
IR BEAMS
J
2K
20P
Q3
STANDBY
+10
OPERATE
3
8
48
FB/BIAS LED
+5D
150
3K
12K
0.1u
2
TO ADC MUX
5
20
Q4
PHOTO-DETECTOR
72
0.2u
0.1u
1K
+5d
100K
270P
76
NTE918
CHARGE INTEGRATOR
10K
20P
270P
1K
+5D
100K
NTE857
78
BAND PASS AMPLIFIER
A
B
NEGATIVE FEEDBACK

FIG. 6A

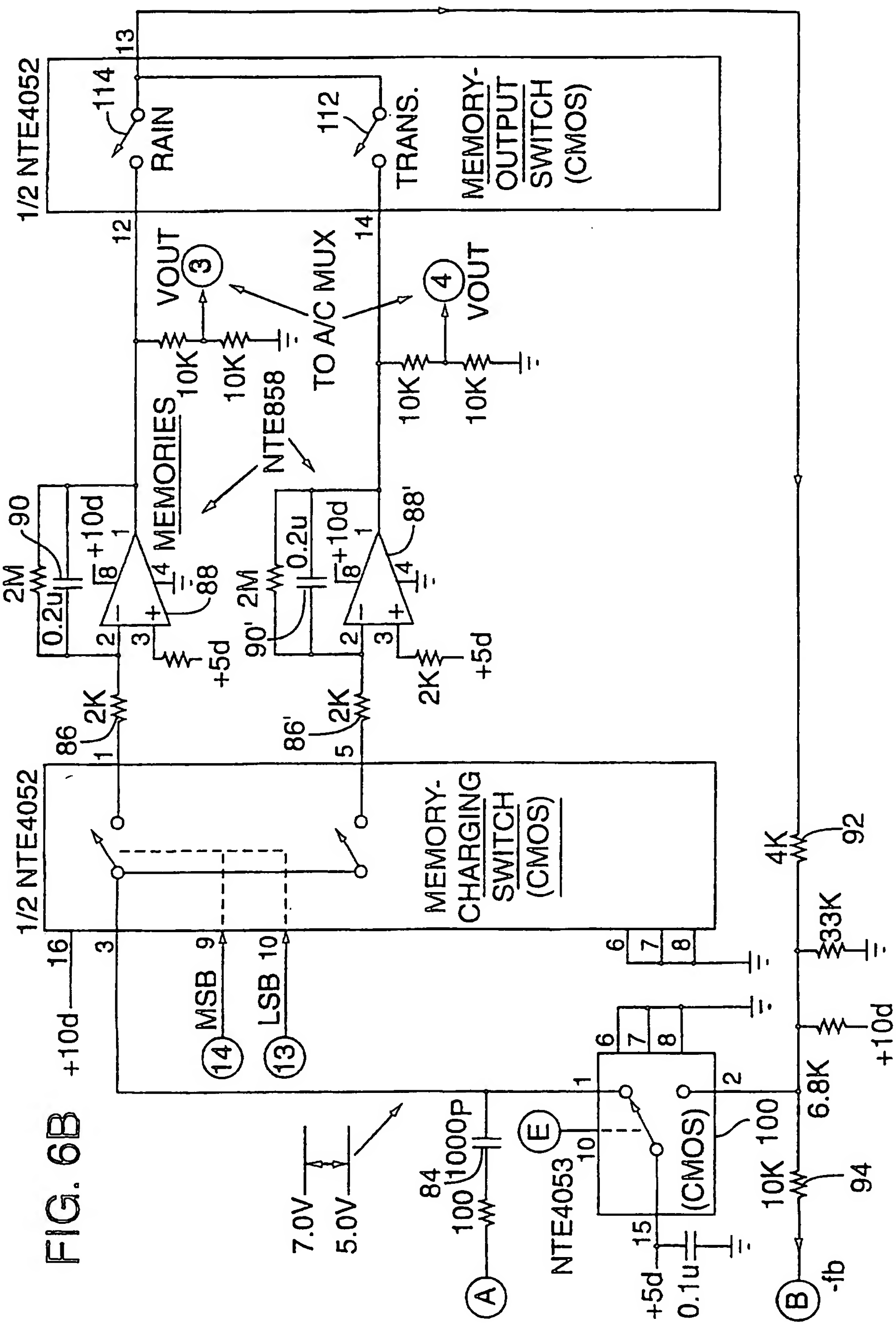

1/2 NTE4052
RAIN
TRANS.
MEMORY-
OUTPUT
SWITCH
(CMOS)
VOUT
TO A/C MUX
MEMORIES
NTE858
1/2 NTE4052
MEMORY-
CHARGING
SWITCH
(CMOS)
MSB
LSB
NTE4053
(CMOS)
7.0V
5.0V
+10d
+5d
-fb

FIG. 6B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/17270

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : H01J 5/16
US Cl. :250/227.14
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 250/227.14, 227.25, 227.18, 227.24, 227.28, 227.29, 574, 341.8; 318/483, 482, 481, 480; 340/555, 556, 557

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

none

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

none

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	US 5,313,072 A (VACHSS) 17 MAY 1994, (17.05.94), see entire document.	1,2,12 — 3,4,14-17
A	US 4,595,866 A (FUKATSU ET AL.) 17 JUNE 1986, (17.06.86), see entire document.	1-20
A	US 4,973,844 A (O'FARRELL ET AL.) 27 NOVEMBER 1990, (27.11.90), see entire document.	1-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents

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"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
05 NOVEMBER 1997	02 DEC 1997

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231
Facsimile No. (703) 305-3230

Authorized officer
Que T. Le
Telephone No. (703) 308-4830